

An Extended Kalman Filter (EKF) to Reconstruct Mars Exploration Rover (MER) Entry and Descent

Michael Lisano
Jet Propulsion Laboratory, California Institute of Technology

Extended Abstract

This paper describes the design and initial test results of an extended Kalman filter that has been developed at Jet Propulsion Laboratory (JPL) for post-flight reconstruction of the trajectory and attitude history of a spacecraft entering a planetary atmosphere and descending upon a parachute. A novel aspect of this filter is that it operates on accelerometer and gyroscope inertial measurement data, as well as altimeter data, as measurements, with explicit (albeit rudimentary) modeling of the vehicle's atmospheric flight dynamics. This is as opposed to the typical "dead reckoning" filter approach, which uses inertial measurement data as direct substitutes for dynamic models. The intent of the filter design is not solely to reconstruct the vehicle's atmospheric flight path, but also to provide statistically correlated co-estimates of the aerodynamic properties of the vehicle (given an atmospheric density profile model known to some prescribed confidence level). Conversely, with different covariance tunings, the same filter could be used to co-estimate the vehicle trajectory and atmospheric density profile (given vehicle aerodynamic coefficients known to some prescribed confidence level).

The filter, named IPANEMA (for Interim Planetary Atmospheric Navigation for Estimation and Mission Analysis) has been developed at JPL to perform rapid post-flight reconstruction of the trajectories of the two NASA Mars Exploration Rovers (MER) that are to arrive at Mars in early 2004. Careful post-flight assessment of the trajectories, aerodynamic properties, and atmospheric properties of the MER entry vehicles is of strategic importance for NASA's continuing program to explore Mars. This is because the MER entry, descent and landing (EDL) subsystem, is a new variant on the architecture of the successful 1997 Mars Pathfinder (MPF) EDL subsystem, and will be used to carry a heavier payload than MPF through a potentially windier and thinner atmosphere. Understanding the performance of the MER EDL subsystem, as an integrated whole operating in-situ at Mars, will enhance the ability to further improve EDL technologies for future exploration at Mars and also at other bodies with atmospheres such as Venus and Titan.

The design of the IPANEMA filter is based on a "core kinematic" state vector designed for generically determining the inertial position and velocity, and body-to-inertial-system quaternion and body rate, as well as kinematically-detected unmodelled translational and rotational accelerations. The core kinematic state vector is one sub-partition of the total state vector, which also includes a measurement model parameter sub-partition and a dynamics model parameter sub-partition. The measurement model parameter sub-partition includes accelerometer biases, gyro biases, and altimeter biases that may be estimated. The dynamics model sub-partition includes coefficients from a simple continuous atmospheric density model, and the drag coefficients of the vehicle and

parachute. The performance of the filter has already been assessed using simulated inertial measurement data based on a Mars atmospheric entry simulation with ideal conditions, as an assessment of the basic mathematical formulation and ability to observe the three-dimensional non-gravitational accelerations acting on the vehicle. These initial results are promising, with an apparent self-correction to significant radial position errors being possible according to the initial results. This self-correction is explored, and results from processing high-fidelity simulation data with simulated measurement errors are discussed, in the paper.

Sampled References

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Condensed Abstract

This paper describes the design and initial test results of an extended Kalman filter that has been developed at Jet Propulsion Laboratory (JPL) for post-flight reconstruction of the trajectory and attitude history of a spacecraft entering a planetary atmosphere and descending upon a parachute. The filter's design enables reconstruction of the vehicle's atmospheric flight path, and co-estimates of either the aerodynamic properties of the vehicle (given an atmospheric density profile model of some prescribed confidence level), or of the vehicle trajectory and atmospheric density profile (given vehicle aerodynamic coefficients of some prescribed confidence level).